# 10. EQUIPMENT CLASS EVALUATIONS USING SCREENING PROCEDURES OR GENERAL GUIDELINES

Chapter 10 contains a summary of equipment class descriptions and parameters based on earthquake experience data, test data, and analytical derivations. The classes of equipment contained in Chapter 10 are not from the SQUG GIP (Ref. 1). Much of the information in Chapter 10 is from DOE references. Table 2.1-4 lists the principal references and authors for the sections in Chapter 10. An item of equipment must have the same general characteristics as the equipment in the screening procedures and general guidelines. The intent of this rule is to preclude items of equipment with unusual designs and characteristics that have not demonstrated seismic adequacy in earthquakes or tests.

The screening procedures in Sections 10.1.1, 10.4.1, and 10.5.1, for evaluating the seismic adequacy of piping, HVAC ducts, and unreinforced masonry (URM) walls respectively, cover those features which experience has shown can be vulnerable to seismic loading. These procedures are a step-by-step process through which the important equipment parameters and dimensions are determined, seismic performance concerns are evaluated, the equipment capacity is determined, and the equipment capacity is compared to the seismic demand. Sections 10.1.1 and 10.4.1 have been technically reviewed and used extensively at several DOE sites including Savannah River Site and Rocky Flats Environmental Technology Center.

The general guidelines for evaluating the seismic adequacy of the equipment classes in the other sections of Chapter 10 cover those features which experience has shown can be vulnerable to seismic loading. The sections contain practical guidelines and reference to documents that can be used to implement an equipment strengthening and upgrading program. The relatively simple seismic upgrades are designed to provide cost-effective methods of enhancing the seismic safety of the equipment classes in Chapter 10. Sections 10.3.1 and 10.1.2 summarize information from portions of a DOE document that has undergone extensive technical review. Sections 10.2.1, 10.2.2, 10.2.3, 10.3.2, 10.5.2, and 10.5.3, on the other hand, are based on walkdown and seismic strengthening efforts at several DOE sites including Los Alamos National Laboratory and Lawrence Livermore National Laboratory.

# 10.1 PIPING SYSTEMS

## 10.1.1 PIPING

This section is the "Procedure for the Seismic Evaluation of Piping Systems Using Screening Criteria", WSRC-TR-94-0343 (Ref. 59) which was developed by the Westinghouse Savannah River Company. Some of the background material for this section is contained in References 52 through 55 and the technical review of this section is summarized in Reference 27.

### 10.1.1.1 Objective

This procedure may be used to evaluate the seismic adequacy of piping systems within the Scope, Section 10.1.1.2, and subject to the Cautions, Section 10.1.1.3.

The procedure may be used alone or with the rest of the DOE Seismic Evaluation Procedure, depending on the piping system's required function, listed in Table 10.1.1-1.

**Table 10.1.1-1 Procedures Applicable to Required Piping System Functions**

| FUNCTIONS | Delivers Flow? | Equipment Operating? | Leak Tight? | Not Fall? | PROCEDURE |
|---|---|---|---|---|---|
| Operability | Yes | Yes | Yes | Yes | Piping Screens and DOE Seismic Evaluation Procedure for Equipment |
| Maintain Integrity of Pressure Boundary | No | No | Yes | No | Piping Screens and DOE Seismic Evaluation Procedure for Equipment Anchorage |
| Position Retention | No | No | No | Yes | Subset of Piping Screens |

Features of a piping system that do not meet the screening criteria are called outliers. Outliers must be resolved through further evaluations (see Chapter 12), or be considered a potential source of seismically induced failure. Outlier evaluations, which do not necessarily require the qualification of a complete piping system by stress analysis, may be based on one or more of the following: simple calculations of pipe spans, search of the test or experience data, vendor data, industry practice, or other appropriate methodology.

10.1.1.2 Scope

This procedure applies to existing (installed), safety or non-safety related, above ground metallic piping or tubing systems constructed of materials listed in ASME B31.1 (Ref. 90), ASME B31.3 (Ref. 91), NFPA (Ref. 92), or AWWA (Ref. 93), with the following restrictions:

1. Pipe materials must be ductile at service temperatures. Cast iron materials are excluded. Non ferrous alloys with a specified ultimate tensile strength (UTS) of less than 30 ksi are excluded. Welded aluminum materials are excluded. Soldered joints are outliers.

2. Diameter-to-thickness ratio (D/t) of pipe must be 50 or less. In terms of pipe thickness (t), the thickness must be greater than the diameter (D) divided by 50.

3. Operating temperature must be below 250°F, but above -20°F.

4. The facility's Seismic Demand Spectrum (SDS) must meet the requirements of Chapter 5.

Commentary

1. While the focus of seismic experience has been mostly on welded steel piping, there is no evidence that welded piping constructed of metals other than gray cast iron has performed poorly in past earthquakes. Test and earthquake experience of piping systems is contained in References 94 through 99.

   Except for aluminum, non ferrous pipe materials allowed by the ASME B31.3 (Ref. 91) code have UTS of 30 ksi or better. Welded aluminum is excluded since many grades of aluminum alloy have low specified ultimate and yield strengths, and tend to have low fatigue strength and limited ductility in the heat affected zone.

   The screens may be used for copper piping. The UTS of weldable grades of copper and bronze piping exceeds 30 ksi. Copper tubing and piping can also be brazed, and a properly brazed joint is stronger than the pipe.

   Soldered joints operating at ambient or higher temperatures exhibit, with time, a reduced strength. At cryogenic temperatures they tend to become brittle. Soldered joints, unlike brazed joints, must be considered outliers.

   Pipe materials must be ductile at service temperatures, having total elongation at rupture greater than 10%. Table 10.1.1-2 shows such properties for common piping materials at room temperature. When judging material ductility, the review team must consider the effect of material degradation on these properties, particularly the potential for reduced elongation caused by lowered ductility.

   Cast iron or brittle elements in a ductile piping system are outliers, but they may be accepted (by other appropriate procedures) if proven to be located in low seismic stress areas, and not susceptible to impact.

   Seismic induced deflection or loads at groove type mechanical joints shall be limited to vendor listed allowables or test based limits.

   Dynamic seismic testing of threaded joint pipe sections indicates that they are prone to leakage under large rotations. For threaded joints, the span between lateral supports, in Section 10.1.1.10, have been reduced accordingly.

2. The seismic testing and earthquake experience data is mostly from standard or thick wall pipe. The screening criteria apply directly to piping systems with a D/t ratio of 50 or less.

3. Below 250°F, thermal expansion loads are small for the purpose of seismic evaluation. The review team should identify unusually stiff piping configurations where the 250°F rule is questionable. Materials lose ductility at low temperatures. Therefore, piping operating below -20°F are considered outliers.

4. Limiting the screening criteria to the specified free field horizontal spectral acceleration is a precaution introduced to remain within the scope of earthquake experience data for equipment.

**Table 10.1.1-2 Typical Properties of Common B31.3 Piping, Tubing, Fitting, and Support Members Materials at Room Temperature**

| DESCRIPTION | MATERIAL | BASIC ALLOWABLE (ksi) | YIELD STRENGTH (ksi) | ULTIMATE STRENGTH (ksi) | ELONGATION IN 2" DIA. ROUND SPECI. (min. %) |
|---|---|---|---|---|---|
| Structural Steel | A36 | 17.8 | 36.0 | 58.0 - 80.0 | 20 - 23 |
| Carbon Steel Pipe | A53, GR. B | 20.0 | 35.0 | 60.0 | 22 - 23 |
| Carbon Steel (Forged Fitt.) | 1A105, FR. CL-70 | 23.3 | 36.0 | 70.0 | 18 - 30 |
| Carbon Steel (Seamless Pipe) | A106, GR. B | 20.0 | 35.0 | 60.0 | 16 - 30 |
| Pipe Fitting | A234 GR. WPB | 20.0 | 35.0 | 60.0 | 14 - 30 |
| Carbon Steel Bolt | A307, GR. B | 13.7 | 36.0 | 60.0 - 100.0 | 18 |
| Stainless Steel Pipe | A312, GR. TP-304L | 16.7 | 25.0 | 70.0 | 25 - 35 |
| Copper Tube | Various types | 6.0 - 15.0 | 9.0 - 40.0 | 30.0 - 50.0 | 25 |
| Red Brass Pipe | B43 Temp. 061 | 8.0 | 12.0 | 40.0 | 35 |

10.1.1.3 Cautions

1. The screening criteria are not meant to be a design tool. The applicable code should be used at the design and layout stage. The screening criteria are not equivalent to compliance with the seismic design requirements of ASME B31.1 (Ref. 90), ASME B31.3 (Ref. 91), ASME

Boiler and Pressure Vessel Code Section III (Ref. 100), NFPA-13 (Ref. 92), AWWA (Ref. 93), AISC (Ref. 81), or AISI (Ref. 101). An existing piping system may comply with the screening criteria but not with the design codes' seismic requirements, and vice-versa.

If a piping system has been designed and constructed to comply with the seismic design provisions of a reference code, it is not necessary to evaluate its seismic adequacy using this procedure. However, the review team may chose to address the provisions of screens 10.1.1.7 "Internal Degradation", 10.1.1.8 "External Corrosion" and 10.1.1.18 "Interaction with other structures" of this procedure, since these considerations are not typically addressed in design codes.

If seismic loads were not included in the original code design of the piping system, the review team may evaluate the seismic adequacy of the non-seismically installed piping system using this procedure, with approval from the owner and/or jurisdiction as appropriate. As an alternative, the review team may evaluate the seismic adequacy of the installed system using the seismic design provisions of the reference code.

2. Application of the screening criteria must reflect the consensus of a seismic review team of two or more degreed engineers, each engineer having the following qualifications (see Section 3.2.2):

    a. a minimum of five years experience in seismic design and qualification of piping systems and support structures

    b. capability to apply sound engineering judgment, based on the knowledge of the behavior of piping systems in actual earthquakes and seismic tests.

3. Qualified users of the screening criteria must complete a training course (see Section 3.2.2) and successfully pass an examination (as appropriate) in the following topics:

    a. content and intent of the screening criteria

    b. piping and pipe support design requirements of ASME B31.1 (Ref. 90), ASME B31.3 (Ref. 91), NFPA-13 (Ref. 92), AWWA (Ref. 93), AISC (Ref. 81), and AISI (Ref. 101)

    c. piping and pipe hanger standards

    d. piping materials and degradation mechanisms

    e. support anchorage rules of the DOE Seismic Evaluation Procedure

    f. earthquake and seismic test experience data for piping systems

4. The screening criteria rely on the considerable body of piping test, earthquake data and analytical design practice to screen and identify the following key attributes which may lead to seismically induced failures of piping systems:

    a. Material condition: Poor construction details and material degradation are at the source of many seismic failures observed in piping systems. Construction quality and material condition are thoroughly covered in the screens.

b. Anchor motion: Excessive anchor motion propagated through equipment and headers has resulted in seismic failures of piping systems. The screens provide for protection against excessive anchor motion.

c. Brittle features: Brittle materials and certain fittings and joints are screened out to avoid non-ductile piping systems.

d. Interactions: Experience data shows several failures traceable to seismic interactions on the piping systems the potential for interactions. Screens are provided to assess the potential for credible and significant interactions.

10.1.1.4 Documentation

The review team shall complete a Piping Seismic Evaluation Work Sheet (SEWS 10.1.1 in Chapter 13) for each piping system. Similar piping systems may be documented in a single SEWS 10.1.1.

The technical basis for judging each screening criterion shall be described on attached sheets and cross referenced in the corresponding notes column of the SEWS 10.1.1.

Written calculations shall be sufficiently detailed to clarify the purpose of the calculation and the conclusion. All assumptions shall be noted.

The method and calculations to resolve outliers shall be documented.

The purpose of each screening criterion is included in this procedure and explained in the required training course.

For each piping system, a complete documentation package will be assembled consisting of the P-SEWS with attached notes and calculations, sketches, and photographs.

Documentation should be sufficient for independent review by an experienced piping engineer trained in the application of this procedure.

10.1.1.5 Required Input

1. Piping System ID

   Record the appropriate piping identification numbers, such as line numbers, chronological numbers, calculation numbers, equipment list item numbers, etc.

2. System Description and Fluid Boundaries

   Piping system descriptions such as system, subsystem, or line number must clearly communicate the scope of the seismic review (boundary points) on a flow diagram sketch. All branch lines shall be identified, and seismic/non-seismic fluid boundaries shall be noted.

3. Piping System Function and Contents

   The contents and function of the piping system during and after the earthquake must be described and categorized as operability, integrity of pressure boundary or position retention (refer to Table 10.1.1-1). For operability, identify active equipment.

4. Piping Layout and Structural Boundaries

Isometric sketches, based on visual inspection, must be sufficient for piping engineers to visualize system response and calculate approximate span equivalent lengths.

Structural boundaries, along with support types and locations shall be noted. If adjacent walls or structures are relied on for seismic restraint, these features shall also be noted. In-line equipment and concentrated masses shall be noted where they contribute to significant weight.

5. Piping System Location and Reference Drawings

Record the piping system location, such as building, floor or room number.

If the piping system spans different buildings or floors, note all locations.

A list of reference drawing numbers and revisions used in the evaluation, such as flow diagrams, piping arrangement diagrams, isometrics, equipment drawings, etc. is required. A separate sheet may be used if needed.

6. Piping Materials and Sizes

List all pipe materials, sizes (nominal pipe size and schedule or thickness) and the references used to determine this information (such as specifications or drawings).

7. Weights

Linear weight (lb/ft) of piping and contents must be recorded for each size of pipe. Noted contents (liquid, gas, air, steam, etc.) must be the same as expected during a postulated earthquake.

Note the linear weight (lb/ft) of insulation and the references used to determine this information (such as specifications or drawings). Record weight of in-line components and eccentricities, as necessary.

8. Concurrent Pressure and Temperature

Specify the pressure and temperature conditions expected concurrent with the postulated earthquake. The pressure values will be used in the component rating screen (refer to Construction Quality). The temperature must be below 300°F for the screens to apply (refer to Applicability Section).

9. Input Response Spectra (see Section 5.2)

The input response spectra are used in several screens and may be necessary for the resolution of outliers.

The review team shall document the appropriate ground and/or floor response spectra, applicable references, and status (final or preliminary). Final response spectra are required to finalize the evaluation.

The ground response spectra (at 5% damping) shall be used for piping supported from grade. (see Section 5.2)

The floor (in-structure) response spectra (at 5% damping) shall be used for piping supported above grade. (see Section 5.2)

If the piping terminal ends are at large flexible equipment, seismic anchor motion of the equipment nozzles shall be considered.

If the piping spans between buildings, the relative anchor motions shall be considered. Relative building movements shall be obtained from the building structural analysis.

10. Applicability

Limits and conditions as given in the Applicability section must be met, to ensure that the material, size (D/t), temperature (250°F and -20°F) and input acceleration of evaluated piping is appropriate for this screening procedure.

10.1.1.6 <u>Construction Quality (Screen 1)</u>

Screen 1 - Piping, components and supports shall be undamaged and of good construction.

<u>Commentary</u>

An assessment shall be conducted of the design, welding, and fabrication quality, as well as all visible damage to the piping and the supports, prior to applying the screening criteria.

The piping system must have been fabricated and examined in accordance with ASME B31.1 (Ref. 90), ASME B31.3 (Ref. 91), AWWA (Ref. 93), or NFPA (Ref. 92).

Pressure ratings for branch connections and fittings shall be checked for adequacy. Systems with pressures in excess of that allowed for ANSI B16.5 (Ref. 102) class 2500 are considered outliers.

Standard pipe fittings manufactured to specifications must have the same pressure rating as their corresponding size and schedule of straight pipe. Unreinforced branch connections, or pipe fittings or couplings unlisted in the applicable standards, or which lack stated pressure ratings, could have significantly lower pressure ratings and seismic capability than their complementary straight pipes, in which case they are outliers.

The piping and supports shall be visually inspected for adequate quality of design, fabrication, installation and maintenance. Instances of poor quality shall be noted. Where piping is not accessible for direct visual examination (covered with insulation, located in inaccessible areas, etc.), construction quality may be based on as-built construction and maintenance records confirmed to be up-to-date.

Signs of poor construction quality or subsequent damage include:

1. excessive distortion of piping or supports

2. brazed joints, apparently of good quality, but without a thin layer of brazing or solder visible where the tube extends beyond the fitting socket

3. uneven, undersized or damaged welds

4. unusual or temporary repairs

5. evidence of interference having caused significant bearing, scratch marks or distortion to the pipe metal or to components

6. a pipe dislodged from its support so that the weight of the pipe is distributed unevenly on the hangers or saddles

7. the deformation of a thin vessel wall in the vicinity of a pipe attachment

8. pipe supports forced out of position by expansion or contraction of the piping

9. the shifting of a base plate, breaking of a foundation, or shearing of foundation bolts of mechanical equipment to which piping is attached

10. missing nuts or bolts

11. signs of leakage (discoloration, dripping, wet surface)

12. cracks in connecting flanges or the cases of pumps or turbines to which piping is attached

13. deterioration of protective coatings, fireproofing or other periodic maintenance conditions

14. general physical damage

15. movement or deterioration of concrete footings

16. failure or loosening of foundation bolts

17. insecure attachment of brackets and beams to the support

18. restricted operation of pipe rollers or slide plates

19. insecure attachment or improper adjustment of pipe hangers

20. broken or defective pipe supports

21. oversized bolt holes

10.1.1.7 Internal Degradation (Screen 2)

Screen 2 - Piping and components shall be free of significant internal degradation.

Commentary

Significant degradation refers to that which may affect the pressure integrity of the piping system. The potential for internal degradation must be investigated and documented from two aspects.

1. the piping system operating performance records, and

2. a metallurgical assessment

It is unnecessary to perform new nondestructive surface or volumetric examinations of the piping system for this screen. The review of performance records and metallurgical assessments are to be based on existing data. If either source of information is unavailable or suggests potential internal degradation, the system must be classified as an outlier.

If the condition of the piping system is judged adequate, but some degradation is expected to occur in the future, the system must be subjected to periodic in service inspection or evaluated for the effects of the expected degradation.

10.1.1.7.1 Operating Performance Record

The system cognizant engineer must identify and assess past maintenance, repairs and replacements performed on the piping system, or on similar systems, to judge if they indicate potential metallurgical or mechanical degradation mechanisms.

The system cognizant engineer must identify any history of abnormal events or loadings, such as flow induced vibration, water hammer, misalignment, binding, and excessive temperature cycling, to judge if they may have caused system degradation due to fatigue or localized yielding.

Evidence of pipe leakage, pipe repair, support failures, or abnormal vibration may indicate significant cyclic loading, which shall be resolved.

10.1.1.7.2 Metallurgical Assessment

The metallurgical assessment of the piping systems must be performed with the help of materials engineering. When considering materials, fluids and operating conditions, the materials engineer must judge the potential for reduced performance capability resulting from material degradation, erosion or corrosion.

10.1.1.7.3 Guidance: Susceptible Areas

The following areas are most susceptible to corrosion, erosion, and other forms of material degradation.

1. points at which condensation or boiling of acids or water is likely to occur

2. points at which acid carryover from process operations is likely to occur

3. points at which naphthenic or other organic acids may be present in the process stream

4. points at which high-sulfur streams at moderate-to-high temperatures exist

5. points at which high- and low-temperature hydrogen attack may occur

6. dead ends subject to turbulence, or where liquid-to-vapor interface or condensation occur

7. valve bodies and trim, fittings, ring grooves and rings, and flange facings

8. welded areas subject to preferential attack

9. catalyst, flue-gas, and slurry piping

10. steam systems where condensation occurs

11. ferrous and nonferrous piping subject to stress corrosion cracking

12. alkali lines subject to caustic embrittlement and resultant cracking

13. areas near flanges or welded attachments that act as cooling fins, causing local corrosion because of temperature differences

14. locations where impingement or changes in fluid velocity can cause local accelerated corrosion or erosion

15. points of accidental contact or insulation breakdown that causes contact of dissimilar metals

16. an area where steam or electric tracing contacts piping handling material such as caustic soda, where concentrated heat can cause corrosion or embrittlement

17. an area immediately downstream of a chemical injection point, where localized corrosion might occur in the reaction zone

18. heat-affected zones (around and in welds) in non-post weld heat-treated carbon steel piping in amine service

19. dissimilar metal welds

20. piping subject to mechanical or flow induced vibration.

The potential for general corrosion or erosion that could result in pipe wall thinning shall be assessed. If wall thinning potential exists in the material or environment, sample measurements shall be taken. If the predicted thinning exceeds 20% of the pipe wall for the planned life of the piping system, the system is an outlier.

If stress corrosion cracking is likely, examinations shall be performed.

The hazard of embrittlement (due to hydrogen, hydrogen cracking, irradiation, thermal aging, etc.) for the planned life of the piping system shall be assessed. If it is possible for pipe ductility (total elongation at rupture) to be reduced by 10% or more, the system is an outlier.

10.1.1.7.4 Guidance: Material Compatibility

The following possible material conditions must be evaluated, along with other service specific conditions:

1. Carbon Steel, and Low and Intermediate Alloy Steels

    a. possible embrittlement when handling alkaline or strong caustic fluids

    b. possible hydrogen damage to piping material when exposed (under certain temperature-pressure conditions) to hydrogen or aqueous acid solution

    c. possible stress corrosion cracking when exposed to wet hydrogen sulfide, and the further possibility of deterioration (sulfidation) in the presence of hydrogen sulfide at elevated temperatures

    d. the need to limit maximum hardness of metals in applications subject to stress corrosion

2. High Alloy (Stainless) Steels

   a. possible stress corrosion cracking of austenitic stainless steels exposed to media such as chlorides and other halides either internally or externally as a result of improper selection or application of thermal insulation

3. Nickel and Nickel Base Alloys

   a. possible stress corrosion cracking of nickel-copper alloy (70Ni-20Cu) in hydrofluoric acid vapor if the alloy is highly stressed or contains residual stress from forming or welding

4. Copper and Copper Alloys

   a. possible dezincification of brass alloys

   b. susceptibility to stress-corrosion cracking of copper-based alloys exposed to fluids such as ammonia or ammonium compounds

   c. possible unstable acetylene formation when exposed to acetylene

10.1.1.8 <u>External Corrosion (Screen 3)</u>

Screen 3 - Piping, components and supports shall be free of significant external corrosion.

<u>Commentary</u>

In reviewing the piping system for signs of corrosion, the seismic evaluation team must consult the materials engineer for questionable conditions.

Significant corrosion refers to metal thickness loss of more than 20%. A surface discoloration or thin layer of rust does not harm structural integrity. Rust forms a surface coating which protects the inner metal from further corrosion.

A loss in thickness can be measured by comparing the pipe diameter at the corroded area with the original pipe diameter. The depth of pits can be determined with a depth gauge.

Stainless steel, copper, nickel, and their alloys are typically used in B31.3 (Ref. 91), and resist atmospheric corrosion. They may be accepted without further review. Iron and carbon (low alloy) steels, however, may be subject to attack, particularly in areas where moisture can accumulate. If piping is insulated and made of iron or carbon/low alloy steel, insulation should be removed at 3 accessible and susceptible points and the pipes inspected for corrosion.

Significant corrosion (uniform loss of more than 20% of metal thickness) can impair the ability of the supports or piping to carry loads. For supports, areas to consider include threaded sections and pipe-clamp or pipe-saddle interfaces. Local metal loss exceeding 20% of the wall thickness may be acceptable, but each occurrence must be evaluated.

10.1.1.8.1 <u>Atmospheric Corrosion</u>

When metals such as iron or steel are exposed to the atmosphere, they will corrode due to the presence of water or oxygen. Below 60% humidity, corrosion of iron and steel is negligible. To prevent atmospheric corrosion, it is necessary to protect the surface of the metal from water by means of a protective barrier or coating.

The normal rate of atmospheric corrosion of unpainted steel in rural atmospheres is low, ranging from 0.001 to 0.007 inches per year. However in some atmospheres, a steel corrosion rate of 0.05 inches per year is possible. The rate of corrosion accelerates at any break in a protective coating because the exposed metal at the break becomes anodic to the remaining metal surface. At such breaks, deep pits will form.

Equipment which is located next to boiler or furnace stacks and exposed to corrosive gases such as sulfur dioxide and sulfur trioxide is subject to accelerated corrosion. These gases, dissolved in water condensate from flue gas, rain, or mist, form dilute acids which act as electrolytes. In addition, chlorides, hydrogen sulfide, cinders, fly ash, and chemical dusts present in industrial atmospheres may act in a similar manner.

#### 10.1.1.8.2 Corrosion Under Insulation and Fireproofing Materials

Inadequate weatherproofing on piping allows moisture to penetrate to the underlying steel, where hidden corrosion takes place. Such hidden corrosion is often severe in refrigeration systems. The skirts of all vessels, regardless of operating temperatures, are subject to severe corrosion under insulation or fireproofing. Cracks in fireproofing concrete, particularly at the top where the concrete ends, also allow moisture to penetrate and hidden corrosion to occur. Protective organic coatings may be useful, especially in seacoast areas where chlorides can come from the air rather than from the insulation. Inhibited insulation, or insulation free of water-soluble chlorides, should be used with austenitic (300 series) stainless steels to prevent stress corrosion cracking.

Defects in protective coatings and the waterproof coating of insulation will permit moisture to contact the piping. When defects are found in the waterproof coating of insulation, enough insulation should be removed to allow the extent and severity of corrosion to be determined. Sections of insulation should be removed from small connections, such as bleed lines and gauge connections, since these locations are particularly vulnerable to atmospheric attack due to the difficulty of sealing the insulation.

#### 10.1.1.8.3 Corrosion of Piping at Contact Points

Piping installed directly on the ground suffers severe corrosion on the underside from dampness. If grass or weeds are allowed to grow beneath and around piping, the underside of the pipe will remain damp for long periods and will corrode. Lines laid directly on supports, or hung by clamps, often show crevice corrosion at the contact points.

Lines that sweat are susceptible to corrosion at support contact points, such as under clamps on suspended lines. Piping mounted on rollers or welded support shoes is subject to moisture accumulation and corrosion. Loss of vapor-sealing mastic from the piping insulation can result in local corrosion. Pipe walls inside open-ended trunnion supports are subject to corrosion. These points should be investigated.

#### 10.1.1.8.4 Corrosion of Structures

Structures that provide crevices where water may enter and remain for long periods are subject to severe corrosion. Examples are structural members placed back to back, and platforms installed close to the tops of towers or drums. Structures located near furnace stacks and cooling towers are particularly susceptible to this type of attack.

10.1.1.8.5 Leakage

The walkdown team must check for the possibility of leaking fluids, suggested by local discoloration or wet surfaces on the pipe or floor.

Bolted joints such as valve packings or flanges may leak. This is especially true for water lines following prolonged periods of sub-freezing weather. Performance records of frozen water pipes show incidents of leakage due to frozen water expanding through and distorting flange gaskets.

Leaks from bolted joints allow fluid to either collect on the pipe or drip onto other systems. In areas where leaks are encountered, the walkdown team should ensure either that the bolts and fluid are compatible or that the bolting has not been subjected to process fluid attack from gasket leakage.

10.1.1.9 Span Between Vertical Supports (Screen 4)

Screen 4 - Piping shall be well supported vertically.

Commentary

A piping system may be considered well supported for deadweight if the equivalent span length between vertical supports, for liquid or gas service, is as shown in Table 10.1.1-3, which lists acceptable vertical support spacing for this screen. The spans in this table correspond to 150% of the ASME B31.1 suggested pipe support spacing provided in Table 121.5. The ASME B31.1 values are based on a bending stress of 2300 psi and a maximum sag of 0.1 inch. Since these values are low, it has been judged reasonable to use 150% of the ASME B31.1 span lengths for installed systems.

**Table 10.1.1-3 Equivalent Span Between Vertical Supports**

| Nominal Pipe Size (in) | Liquid Service (ft) | Gas Service (ft) |
|---|---|---|
| 1 | 10 | 13 |
| 2 | 15 | 19 |
| 3 | 18 | 22 |
| 4 | 21 | 25 |
| 6 | 25 | 31 |
| 8 | 28 | 36 |
| 12 | 34 | 45 |
| 16 | 40 | 52 |
| 24 | 48 | 63 |

The equivalent span length $L_{ei}$ in a given direction i is defined as: $L_{ei} = (W_{pi} + W_{ci}) / W$, [ft]

$W_{pi}$ = Weight of pipe length in span between consecutive supports in direction i, including insulation and contents [lb]

$W_{ci}$ = weight of in line components in span [lb]

W = weight per unit length of pipe size, insulation and contents in span [lb/ft]
The equivalent span length for gas service may be used for evaluating empty, normally dry, pipe spans.

Vertical loading can be resisted by engineered deadweight supports, or structures that are not considered deadweight supports, such as penetrations through walls, certain types of box beam horizontal restraints, and floor slabs.

The following vertical support configurations shall be considered outliers in seismic screening evaluations.

1. friction clamp connections

2. shallow pipe saddle support or pipe rolls

3. bottom support if not positively attached to the pipe and floor, and if the lateral movement of the pipe could possibly tip the support

4. pipe resting on a support, free to slide laterally so as to fall off the support

5. A clamp on a vertical riser without positive attachment to the pipe, such as lugs above the clamp.

10.1.1.10 <u>Span Between Lateral Supports (Screen 5)</u>

Screen 5 - Piping shall be sufficiently restrained in the lateral direction.

<u>Commentary</u>

A piping system may be considered sufficiently restrained in the lateral direction if the equivalent lateral span length for liquid or gas service does not exceed three times the spans in Table 10.1.1-3, which corresponds to 4.5 times the ASME B31.1 (Ref. 90) suggested vertical pipe support spacing. This span is to be divided by 2.3 (stress intensification factor for threaded joints) for pipe sections which contain threaded joints.

The 4.5 times the B31.1 deadweight spans for spacing of lateral restraints is consistent with the current draft ASME B31 Mechanical Design Committee Appendix on Seismic Design (Ref. 103). Seismic experience data has indicated that relatively long spans have experienced lower spectral accelerations and are more susceptible to displacement-induced damage. Therefore, actual spans between lateral supports will often be limited to less than 4.5 times the B31.1 deadweight spans by Screen 6 (anchor motion of headers), Screen 9 (equipment nozzle loads), or Screen 12 (pipe support).

Lateral restraint may be provided either by an engineered lateral support, or by other means, such as:

1. Interferences

Lateral interferences will limit motion in piping routed along a wall or structural member. Although this restraint occurs in one direction only, it significantly restricts the response of the system to a reversing load.

2. Box Beam

A box beam, while not designed to provide horizontal restraint, will do so once the pipe moves through the gap and contacts the beam. When evaluating the effectiveness of a box beam's horizontal restraint potential, the gap on both sides of the pipe must be considered. Note that, should the pipe impact the vertical members of the beam, significant energy is dissipated and the frequency response of the system is modified.

3. U-Bolts

U-bolts provide significant horizontal restraint, even when the side load design capacity of the U-bolt is exceeded. Should the U-bolt yield under seismic stress, it will bend, resisting horizontal motion by tension. U-bolts should not be considered to provide longitudinal restraint along the pipe axis.

4. Saddles

There are generally two types of pipe saddle supports; a simple saddle on which the pipe merely rests, and that which includes a yoke (strap or U-bolt) to restrain the pipe in the saddle. A shallow simple saddle provides practically no horizontal restraint, and could permit the pipe to escape from its support during a seismic event. A deep saddle support will restrain the pipe in the lateral direction.

5. Floor and Wall Penetrations

Piping often passes through openings in floors, grating or walls. Since these openings are not designed as supports, gaps between the pipe and the structure exist. When made in floors or walls, the openings are usually secured by a sleeve; in gratings, a sleeve or a ring is used. These penetrations provide significant lateral restraint during dynamic seismic events and, like the box beam, prevent displacement, dissipate energy and modify system frequency.

6. Rod Hangers

The lateral support capacity of rod hangers is measurable as a function of the swing angle of the rod when subjected to a given lateral load. While this lateral support capacity is not provided by design, it can be important in practice. The length of the rod is significant because for shorter rods, the swing angle and resistance to horizontal displacement is greater. An effective lateral spring rate formula for short rod hangers is $W/l$, where $W$ is the tributary weight on the rod and $l$ is the length of the rod.

10.1.1.11 Anchor Motion (Screen 6)

Screen 6 - Piping must have sufficient flexibility to accommodate the seismic motions of structures, equipment and headers to which it is attached.

Commentary

One of the most common causes of piping failure in strong motion earthquakes is seismic anchor motion (SAM) resulting from:

1. large displacement of unanchored tanks or equipment
2. failure of the tank or equipment anchorage
3. large differential motions of structures to which the piping is attached
4. large motions of header piping induced into smaller branch piping
5. differential movements due to soil settlements

SAM caused by these sources imposes large strains in rigid sections of the piping system. Most of the common piping failures are in pipes with non-welded connections to tanks, pumps, and larger header pipes which are insufficiently restrained.

In order to screen out SAM as a potential failure mode for piping, the following conditions must be evaluated; otherwise the effect of anchor motion must be calculated.

1. Tanks and equipment to which the piping attaches must be properly anchored to prevent sliding, rocking or overturning. Equipment anchorage shall be evaluated using Chapter 6 and Section 9.1 of the DOE Seismic Evaluation Procedure.

2. Tanks and equipment to which the piping attaches, and the supports for the tanks and equipment should be relatively stiff to minimize SAM.

   Note: When vibration isolators are present, vibration isolators on equipment are a source of SAM, and must be evaluated as provided in Chapter 6 of the DOE Seismic Evaluation Procedure. If there are no seismic stops built into the isolators, the equipment will likely require the addition of seismic restraints to limit motion. If seismic stops are installed with the vibration isolators, the attached piping must be assessed for the maximum motion that can be realized before impacting the stops.

3. Piping rigidly attached to two different buildings, or substructures within a building, must be sufficiently flexible to accommodate the differential motion of the attachment points. Usually, structural displacements are relatively small, and the motion can be easily accommodated by pipe bending. Particular attention should be focused on piping that has its axial motion restrained at support points in two different structures

4. Header motion imposed on small branch lines must be assessed, or the header must be restrained near the branch.

The elastically calculated unintensified stress amplitude due to SAM (M/Z) may be limited to twice the material yield stress for screening purposes. When considering lateral movement of header pipes and restraint of branch pipes, it is necessary to define a lateral restraint, as discussed in Section 10.1.1.10, Lateral Span.

10.1.1.12 Mechanical Joints (Screen 7)

Screen 7 - Piping shall not contain mechanical joints which rely solely on friction.

Commentary

The seismic experience data contains a number of instances where mechanical joints which rely on friction have leaked. While it is not clear whether this leakage was due to seismic anchor motion effects (already covered by an earlier screen), these joints must be classified as outliers pending further studies. Joint vendors may be contacted or tests may be conducted to obtain allowable loads, and simple span formulas may be used to estimate applied loads to be compared to the allowables.

10.1.1.13 Flanged Joints (Screen 8)

Screen 8 - Flanged joints shall withstand the expected seismic moments without leakage.

Commentary

Flanged joints have leaked under severe seismic loads, and sometimes may leak under normal service loads. If the flanged joint is a B16.5 (Ref. 102) flange adequate preload, and a rated pressure above the operating pressure, the flange is acceptable. Other flanged joints with lesser capacities should not be located in high stress areas. One method of assessing moment capacity at flanges is to determine excess pressure capability (rating minus operating pressure) and convert that into an equivalent moment. The rated pressure of flanged joints shall be established.

If there are indications of leakage at the joint in past service, the flanged joint is an outlier.

Slip-on flanges are only acceptable if located in areas of the piping system with estimated unintensified seismic stress less than approximately 10,000 psi.

10.1.1.14 Equipment Nozzle Loads (Screen 9)

Screen 9 - Equipment shall not be subjected to large seismic loads from the piping systems.

Commentary

To be considered operable, active equipment and components (such as pumps and valves) have to meet the requirements of the DOE Seismic Evaluation Procedure (refer to Table 10.1.1-1), in addition to the following requirements:

Equipment and component nozzles, except for valves that are stronger than the pipe, should be protected, by appropriate restraints, from excessive seismic loads, particularly where the equipment nozzle or joint is of smaller size than the pipe. The piping layout shall be reviewed to evaluate that large seismic loads are not reacted at the equipment nozzle. One potential problem is a long axial run of pipe not restrained from axial movement except at the equipment nozzle. If there is a possibility of large seismic loads, the unintensified bending stress at the nozzle shall be elastically evaluated and compared to twice the material yield stress.

Piping reaction loads at the nozzles of rotating equipment may affect their function. The seismic reaction loads imparted by the piping on the nozzle of the active (rotating) equipment shall be estimated. These loads shall be small (unintensified bending stress less than 6000 psi), or within the estimated capability of the equipment.

### 10.1.1.15 Eccentric Weights (Screen 10)

Screen 10 - Eccentric weights in piping systems shall be evaluated.

Commentary

The adequacy of valves with eccentric operators shall be evaluated using the rules in Chapter 8 of the DOE Seismic Evaluation Procedure. Eccentric pipe segments, such as unsupported vents or drains, shall be evaluated using the peak spectral acceleration at 5% damping (or a better estimate of the spectral acceleration at the pipe frequency) (see Section 5.2) and an allowable unintensified elastically calculated stress of twice the material yield stress.

### 10.1.1.16 Flexible Joints (Screen 11)

Screen 11 - Flexible joints shall be properly restrained to keep relative end movements within vendor limits.

Commentary

For unsupported flexible joints such as expansion joints, bellows, or flexible joints, the relative displacements need to be limited to prevent tearing or buckling the joint. Where manufacturer's limits can be exceeded, the Review Team should ensure the joint has sufficient mobility to absorb the seismic deflections. When such joints are adequately supported on either side this is not usually an issue.

If the configuration is such that excessive seismic movements at the expansion joint could tear or buckle the joint, the expansion joint is an outlier. Calculation of seismic displacements and comparison to established allowable displacements are required to resolve the outlier.

The seismic evaluation team may refer to the rules of the Expansion Joints Manufacturers Association (EJMA).

### 10.1.1.17 Evaluation of Pipe Supports (Screen 12)

Screen 12 - Pipe supports shall be capable of withstanding seismic loads without failure.

Commentary

Support failure refers to non-ductile rupture or complete loss of restraining function of the pipe support.

The review team shall evaluate the seismic load and capacity of supports judged to be prone to failure. The basis for the support selection shall be documented.

Examples of supports to be evaluated are:

- supports with largest spans or close to heavy components
- supports reacting the load from long axial runs
- short rods adjacent to longer rods
- stiff support in the midst of significantly more flexible supports (hard-spot)

- supports with fewest or smallest anchor bolts
- gang supports reacting loads from several pipes
- supports not attached to structural steel or concrete (such a supports attached to other piping, cable tray or transite walls)

10.1.1.17.1 Seismic Demand

The calculation of horizontal and vertical seismic loading on pipe supports is based on the tributary weight of adjacent piping spans multiplied by one of the following factors:

1. For piping supported from grade, multiply by the peak of the 5% damped ground response spectrum. (see Section 5.2)
2. For piping supported above grade, multiply by the peak of the 5% damped floor (in-structure) response spectrum. (see Section 5.2)

10.1.1.17.2 Seismic Capacity

Where failure is credible, the review team shall evaluate the seismic capacity of support members along the seismic load path. The capacity of support members, welds and joints may be estimated using AISC (Ref. 81) rules, multiplying the AISC allowables by 1.7. Where manufacturer design limits are provided for standard pipe support elements (excluding anchor bolts in concrete), the seismic capacity may be taken as twice the design limit for members loaded in tension, bending or shear. For compression members, if the design limit is based on buckling, the seismic capacity shall be the same as the manufacturer design limit.

For cold-formed steel members, the stress allowables for seismic screening may be 1.7 times the AISI Specification for those members.

Anchorage shall be inspected, and capacity calculated and documented, using the rules of Chapter 6 of the DOE Seismic Evaluation Procedure.

The review team must take care to limit their calculations to credible failure modes which can hinder the function of the piping system. Limited yielding is, in most cases, not a credible failure mode.

An explicit calculation of weld capacities is not required if the welds are estimated to be the same size, and develop the same strength, as connecting members.

The fatigue capacity of threaded rod hangers with fixed-end connections to the wall or structural steel, may be evaluated using the fatigue evaluation screening charts for raceway supports in Section 9.2.1 of the DOE Seismic Evaluation Procedure.

10.1.1.18 Interaction with Other Structures (Screen 13)

Screen 13 - The piping being reviewed shall not be a source or target of interactions.

Commentary

A piping system subjected to seismic loads will displace or swing laterally, and may impact adjacent components.

10.1.1.18.1 Estimate of Displacement

Without detailed analysis, lateral displacements or swing deflections of piping spans can be estimated.

An approximate formula to estimate pipe displacements (Sd [in]) at spectral acceleration ($S_a$ [in/sec$^2$]) for a pipe frequency f [1/sec], is:

$$S_d = 1.3\ S_a / (2\ \pi\ f)^2$$

where 1.3 is the mode participation factor for a simply supported beam. An approximate upper bound for a 0.3g Regulatory Guide 1.60 "Design Response Spectra for Seismic Design of Nuclear Power Plants" (Ref. 104) spectrum at low frequency (less than 0.25 Hz) is about 28" for 5% damping. Actual displacements of piping systems which meet the screens are rarely larger than 12".

10.1.1.18.2 Estimate of Impact Consequences

In all cases, the review team will have to carefully estimate the extent of pipe deflection and the component's capacity to absorb impact.

Generally, impact must be avoided if it affects the following components:

- active equipment (motors, fans, pumps, etc.)
- instrumentation
- tubing
- unstable or light weight structures
- electrical cabinets and panels
- sprinkler heads

Generally, impact may be of little consequence if it affects the following components:

- walls
- large frames or structures
- passive components (tank, check valve, etc.)
- pipes of approximately the same or larger diameter

In all cases, the review team must use judgment in estimating the extent of movement of the pipe under review and the capacity of the impacted equipment.

The review team shall visually inspect all structures and commodities located above the pipe and identify those hazards which are judged to be credible (may fall on the pipe) and significant (fall impact may cause pipe failure as defined in Table 10.1.1-1). The guidance in Chapter 7 of the DOE Seismic Evaluation Procedure for equipment interactions may be used for this evaluation.

## 10.1.2 UNDERGROUND PIPING

### 10.1.2.1 Scope

This section addresses the seismic evaluation of underground, single wall, pressure piping made of steel, ductile iron, or copper material. Pipe materials must be ductile at service temperatures. Ductile pipe behavior requires joints which are stronger than the pipe. Arc-welded or properly brazed joints are examples of ductile pipe design. Oxy-acetylene welded joints in steel pipes must be considered an outlier and evaluated in accordance with Section 10.1.2.6.

Single or double containment piping (comprised of a core pipe contained inside a buried jacket pipe, as is commonly the case for radioactive waste transfer lines) are covered in Chapter 7 of Reference 29 ("Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Tanks and Appurtenances," BNL 52361). This reference provides a rigorous methodology for evaluating underground piping. Additional guidance for evaluating underground piping is available in the "ASCE Guidelines for the Seismic Design of Oil and Gas Pipeline Systems" (Ref. 105) and ASCE 4 (Ref. 74).

Underground piping made of gray cast iron, non-ferrous alloys, welded aluminum, thermoplastics, fiberglass, reinforced concrete, and asbestos-cement may exhibit non-ductile behavior and must be considered an outlier. In addition, threaded joints, groove type mechanical joints, and flanged joints must be considered outliers as seismic induced displacements must be explicitly evaluated and compared to joint allowables. Mechanical joints which rely solely on friction are also considered outliers as they may have very low displacement capacity. Methods for dealing with outliers are described in Section 10.1.2.6.

### 10.1.2.2 Pipe Condition Assessment

The seismic evaluation of underground piping must include an assessment of the existing pipe condition with verification that there has not been significant degradation in the strength, ductility, wall thickness, and joint integrity. This assessment includes:

1. Confirmation of the compatibility of the pipe material, exterior coating, interior lining (where provided), with the conveyed fluid and the surrounding soil or backfill.

2. Examination of historical performance data and maintenance records for evidence of leakage or repairs.

3. A visual and volumetric examination of selected sections of the piping (which will have to be excavated at examination points) to confirm the soundness of materials and joints.

Should this assessment identify a problem with the existing pipe integrity, the piping should be considered an outlier. Piping designated as an outlier should be investigated over a larger extent of the pipe length than the selected sections to identify the entire extent of piping with the problem. Mitigation of piping integrity necessitates repair or replacement of the affected pipe length.

### 10.1.2.3 Applied Loads

Seismic loads acting on underground piping include wave passage directly inducing strains in the pipe, transient seismic anchor motion from differential movement of building or other structures to which the pipe is attached, and permanent seismic anchor motion from soil movements resulting from seismic induced liquefaction, lateral spreading, settlement, or landslides. Seismic loads are also induced by differential movement resulting from fault rupture intersecting underground pipe.

Concurrent non-seismic loads might include internal pressure, soil overburden and surface loads, thermal expansion, and natural soil settlements.

#### 10.1.2.4 Evaluation of Piping for Wave Passage Induced Strains

Typically, underground piping constructed of ductile materials and ductile joints can safely withstand strains induced by wave passage effects during an earthquake. In addition, underground piping constructed of ductile materials and ductile joints can safely withstand transient differential movements of underground portions of buildings or other underground attachment points during seismic wave passage. In general, no explicit analysis is required in these cases. Analyses or detailed evaluation is required for the following cases:

- impedance mismatch between soils, such as soft soil to stiff rock
- bends in the piping at which there can be stress concentration effects
- piping which passes through the interface of a building to its supporting soil
- locations of excessive pipe corrosion

It should be noted that there is one reported case of seismic wave propagation induced pipe failure to a corrosion free modern continuous welded steel pipeline. This case study is described in Reference 106 in which it is believed that the case study is the only documented case of wave passage damage to modern welded steel underground piping. This case has very extreme parameters, as discussed in the following paragraph, which should be considered when evaluating underground piping for wave passage effects and designated underground piping as an outlier. It is unlikely that a similar combination of circumstances exist at a DOE facility.

The pipe, which is discussed in Reference 106, was damaged in the 1985 Michoacan Earthquake. The pipe was a 42 inch diameter, 5/16 inch wall thickness water pipe constructed in the early 1970's of API 120 X-42 grade steel (yield stress = 42 ksi). The pipe centerline was about 6.4 feet below the ground surface. The soil profile consists of 130 feet very soft clay underlain by two stiffer strata of 260 feet and 1300 feet thickness atop rock. The pipe failure was wrinkling and tearing of the pipe wall. Three factors contributed to the failure of this pipe (1) the ground motion was dominated by Rayleigh waves as the earthquake source was very distant from the pipe location; (2) the peak ground velocity was very high for the acceleration level as the observed PGV/PGA was about 170 in/sec/g instead of 48 in/sec/g given by Newmark for alluvium; and (3) the soil was extremely soft with a shear wave propagation velocity of only about 130 feet per second.

Other examples of ductile underground piping subjected only to seismic wave propagation have demonstrated very good pipe performance. It is judged that the one case of observed damage resulted from a very unusual combination of circumstances. If conditions approach those described for this case, the ductile pipe must be designated an outlier and appropriate analyses can be used to evaluate this piping.

#### 10.1.2.5 Evaluation of Piping for Permanent Soil Movements

Underground piping at sites subjected to permanent soil movements due to settlement, lateral spreading, liquefaction, landslides, or fault displacement must be considered an outlier. In these conditions, the pipe must be evaluated in the manner described in Section 10.1.2.6.

10.1.2.6 Outlier Evaluation

Underground piping designated as an outlier must be explicitly evaluated for the ability of the pipe and joints to withstand seismically-induced soil movements, either transient wave passage effects or permanent ground movements. The preferred approach is to evaluate pipe deformations imposed during earthquake motion and associated effects and to compare to strain criteria developed from full scale pipe tests. In some cases, pipe stresses are evaluated and compared to empirically determined stress limits. Analytical techniques must account for non-linear pipe behavior as acceptable strains may be beyond the elastic limit. Analytical techniques must also account for the non-linear stiffness of the soil surrounding the underground piping.

A method for estimating pipe strains induced during earthquake wave passage is completely described in Chapter 7 of Reference 29. The approach involves estimating axial strain and curvature of the ground during seismic wave passage. These strains may be transferred to long straight runs of buried piping by friction or bearing. Strains (or stresses) at elbows, bends, and tees are then determined by pseudo-static beam on elastic foundation analysis subjected to the axial strain and curvature of the surrounding soil. In such an analysis, the piping system, including both straight and curved sections, are modeled by relatively simple beams supported by linear Winkler springs representing the confinement of the surrounding soil. Similar analysis may be used to determine pipe response due to transient differential movements of buildings or other structures to which the pipe is attached/anchored. By this approach, strains and stresses may be determined for straight pipe, elbow, bend, and tee configurations, and at joints. The resulting strains or stresses should be compared to allowable levels depending on the ductility and strength of the pipe material and of the deformation capacity of joints.

For underground pipe at sites subject to permanent differential soil movement, considerable effort must be expended to establish the amount of movement, the rate of movement, the direction of movement, and the area impacted by the movement. In such cases, the preferred solution is to mitigate the soil such that movements do not occur or to reroute the pipe to avoid the affected area. If this is not possible, underground pipe evaluation is typically performed by conducting analysis of non-linear representations of the pipe and surrounding soil subjected to conservative estimates of the permanent ground deformation caused by settlement, spreading, liquefaction, or landslide. The resulting pipe response is compared to empirically based pipe strain criteria. In some cases, it may be possible to evaluate the pipe using the pseudo linear beam on elastic foundation analysis described in Chapter 7 of Reference 29 and discussed above for wave passage effects. Guidance on the evaluation of underground piping subjected to fault displacement is provided in Reference 105. The allowable strain criteria in Chapter 7 of Reference 29 is more conservative than that in Reference 105.

## 10.2 MECHANICAL EQUIPMENT

### 10.2.1 HEPA FILTERS

This section describes general guidelines that can be used for evaluating and upgrading the seismic adequacy of HEPA Filters which are included in the Seismic Equipment List (SEL). The guidelines contained in this section are based on experience at Los Alamos National Laboratory as well as other DOE sites. Guidelines in this section cover those features of HEPA filters which experience has shown can be vulnerable to seismic loadings.

HEPA filters are generally used to prevent airborne radioactive material from being released to the environment. The environment may be a laboratory room, a facility, or external to a facility.

Filters attached to a glove box (see Figure 10.2.1-1) are used to limit the spread of radioactive material through out the ventilation system of a facility. By the "rule of the box" (see Section 2.1.3.4.1), these types of filters can be evaluated as part of the glove box. The evaluation of the equipment class of glove boxes is discussed in Section 10.2.2.

Filters which are used to scrub recirculating air in a facility or which scrub air that is released through the facility exhaust are generally found in filter plenums (see Figures 10.2.1-2 through 10.2.1-4). Filter plenums are generally similar to the equipment class of Air Handlers, which is discussed in Section 8.2.9, with the exceptions that there may not be a coil section and the fan may be external to the plenum structure. Therefore, the caveats given for Air Handlers in Section 8.2.9 can be used in the evaluation of HEPA filters. In addition, external fan units associated with filter plenums can be evaluated using the caveats given for the equipment class of Fans, as discussed in Section 8.2.10.

HEPA filters themselves are generally lightweight and firmly held in position to a frame by some type of restraining mechanism. Both the frame and the restraining mechanism need to be evaluated. The frame should be evaluated for overall stability and to determine if permanent deformations can take place that adversely affect the function of the filter bank. The restraining mechanisms should be reviewed to determine if the filters can come loose during an earthquake. Seismic evaluations should include not only the equipment the filters are installed in, but also the framing and restraining mechanisms within those pieces of equipment.

HEPA filters should also be reviewed for potential seismic interactions. One such interaction would be the effect of fire suppression water on the filter functionality. Should fire sprinklers activate during or following a seismic event and spray water on the HEPA filters, the HEPA will weaken and may fail to function as intended. In addition, should a seismic induced fire occur during or following an earthquake and the fire suppression fails to activate, heat from the fire could adversely affect the functionality of HEPA filters.

**Figure 10.2.1-1 HEPA filters are contained in stainless steel canisters bolted to the tops of these glove boxes.**

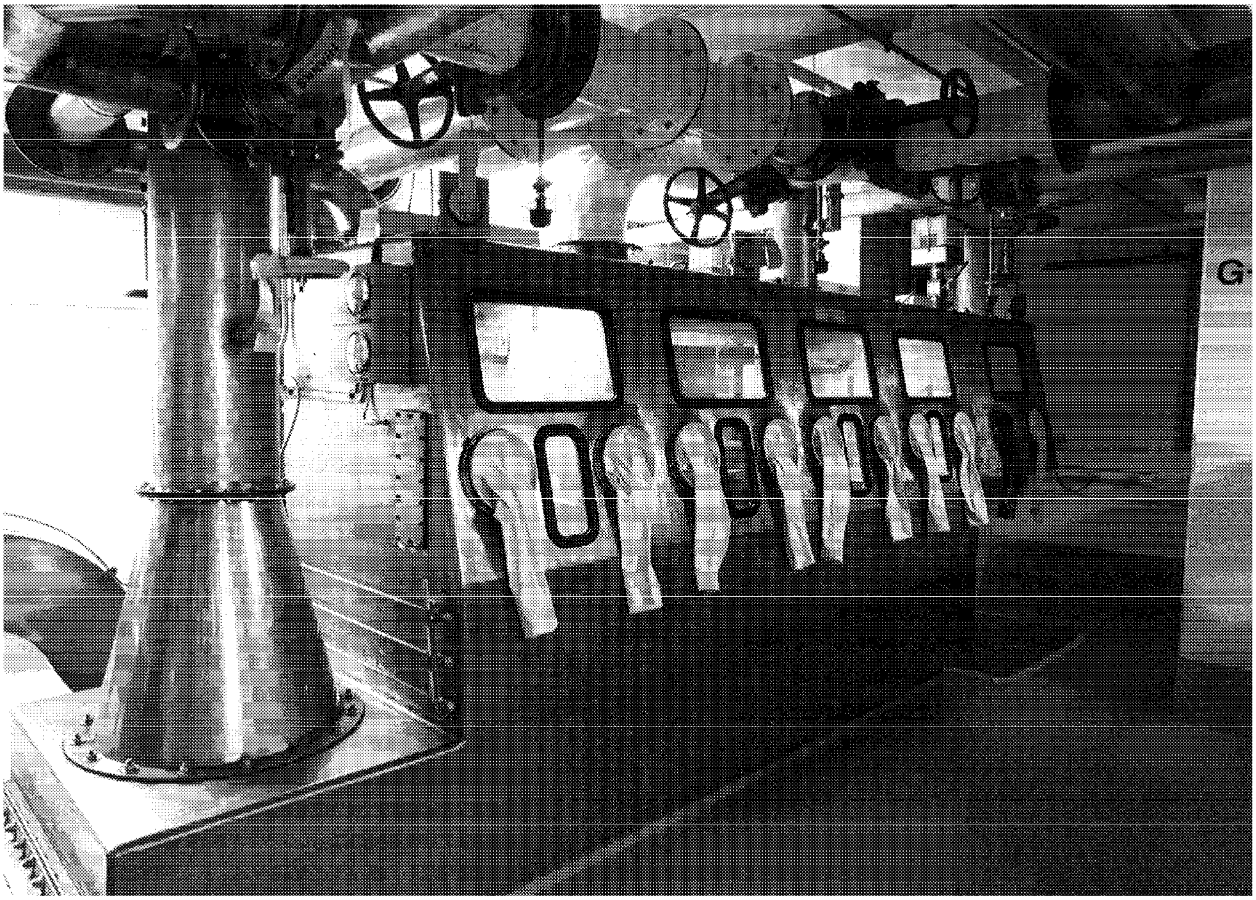

**Figure 10.2.1-2 This filter plenum containing a series of HEPA filters is similar to a glove box.**

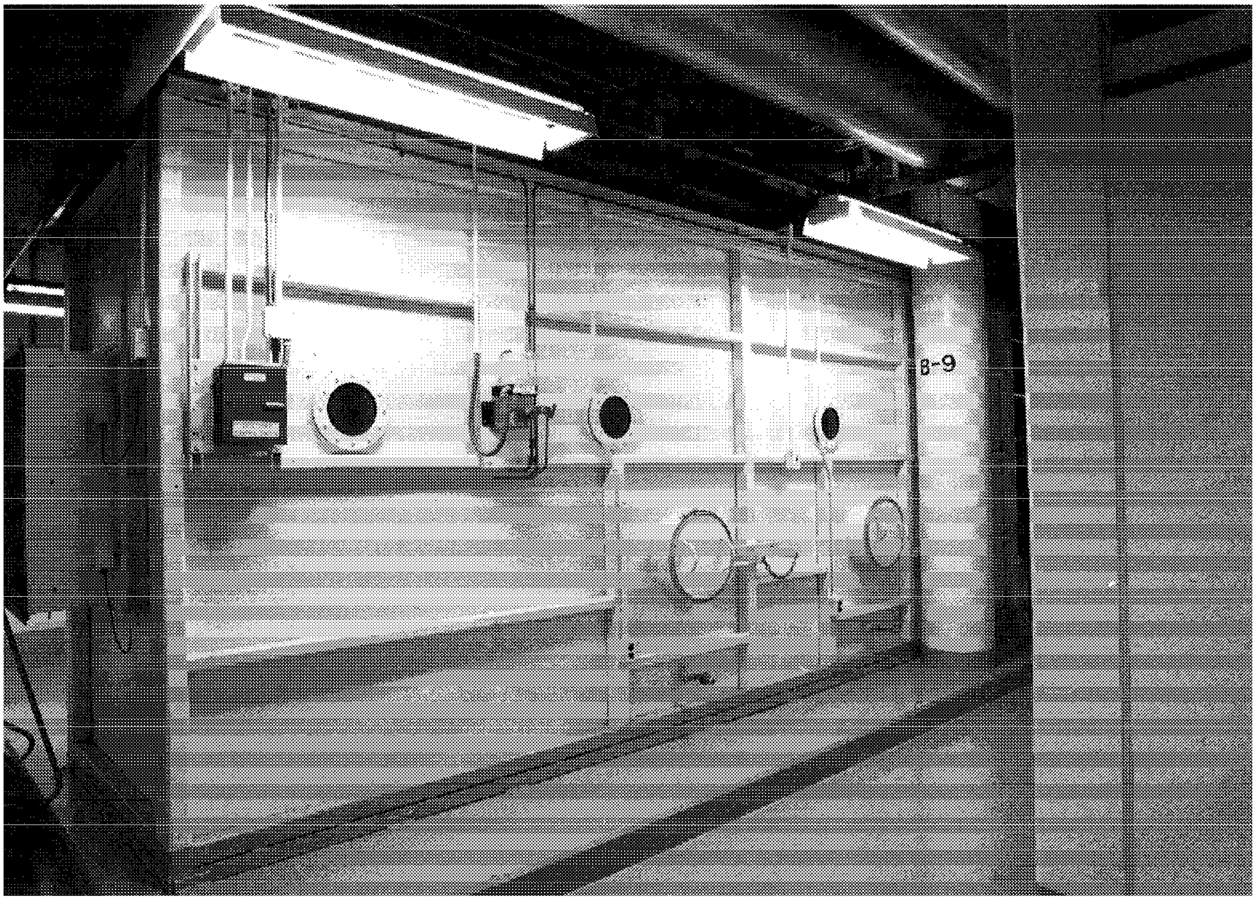


Figure 10.2.1-3 This filter plenum contains a series of HEPA filters and is constructed of structural steel tube frames with continuously welded steel plates for the walls, floor, and roof.

Figure 10.2.1-4 HEPA filters (on the left side of the photograph) are securely held to the structural steel tube frame by bolted clamps (not shown). Also shown are dampers which are typically associated with filter plenums.

### 10.2.2 GLOVE BOXES

This section describes general guidelines that can be used for evaluating and upgrading the seismic adequacy of glove boxes which are included in the Seismic Equipment List (SEL). The guidelines contained in this section are based on analytical and walkdown experience at Los Alamos National Laboratory as well as other DOE sites. Guidelines in this section cover those features of glove boxes which experience has shown can be vulnerable to seismic loadings.

Glove boxes (see Figure 10.2.2-1) serve as primary confinement for radioactive or hazardous materials. As such, the pressure inside a glove box is less than the room pressure external to the glove box. Therefore, maintaining the pressure boundary is important when evaluating the seismic adequacy of glove boxes.

In evaluating glove boxes, the following five areas should be evaluated:

- seismic interaction effects, including flexibility of attached tubing and conduit and interaction with components or equipment located inside the glove box (heat sources, furnace, vacuum chamber, or flammable materials)
- load path
- supporting frame work
- leak tightness
- anchorage

As with other equipment, glove boxes are vulnerable to interaction effects. Windows, gloves and instrumentation tubing are all examples of fragile components associated with glove boxes that are prone to interaction effects. Interactions which should be considered include those that are both internal and external to the box. Externally, components such as power supplies and furnaces, which directly support glove box activities, should be restrained to prevent impact with windows (see Figure 10.2.2-2) and support frames. Internally, objects such as conveying systems and machining tools should be anchored to the box so that they cannot slide and tear gloves and break windows. Attached tubing and conduit need to have enough flexibility to accommodate the seismic motion of the glove box. Glove boxes which depend upon moment-resisting frame action for resistance of lateral seismic loads are more flexible than those using bracing and are therefore more susceptible to tubing and conduit failures. Additional guidance on evaluating the effects of seismic interaction is provided in Chapter 7.

The load path associated with the glove boxes needs to be evaluated. Load path refers to the manner in which inertial loads acting on the glove boxes and associated equipment are transferred through the glove box structure to the supporting framework, to the anchorage, and into the supporting structure. During seismic evaluations, the load path, including connections, should be carefully reviewed for adequate strength, stiffness, and ductility. Attachments, such as filtration devices and furnace wells, should be adequately anchored to the box. In addition, the box should be adequately attached to the supporting framework.

The supporting framework of glove boxes is one aspect of the evaluation in which structural calculations may be necessary to determine seismic adequacy. The framework should be reviewed for missing or altered (cutouts, notches or holes) members. Frames which rely on moment connections to provide lateral support and are constructed of unistrut or single angle legs have been found to be especially vulnerable. Braced frames are generally less vulnerable.

As previously noted, glove boxes serve as primary confinement for radioactive or hazardous materials. As such, leak tightness is an important feature of the glove box system. Interaction effects, load path, and supporting framework, in particular the relative displacements with connections boxes and attachments, could jeopardize the integrity of the pressure boundary associated with a glove box.

As with most equipment, anchorage should be evaluated using the procedure in Chapter 6. An area of concern which should be reviewed carefully is the gap between the bottom of the base plate and the floor. In many cases an individual glove box is part of a system or train of glove boxes in which one box is connected to another box. To maintain proper vertical alignment of the boxes, shims are typically used beneath the base plate (see Figure 10.2.2-3). These shims can introduce bending to the anchor bolts which can significantly reduce the capacity of the bolts. The reduction of bolt capacity due to bolt bending is briefly discussed in Chapter 6.

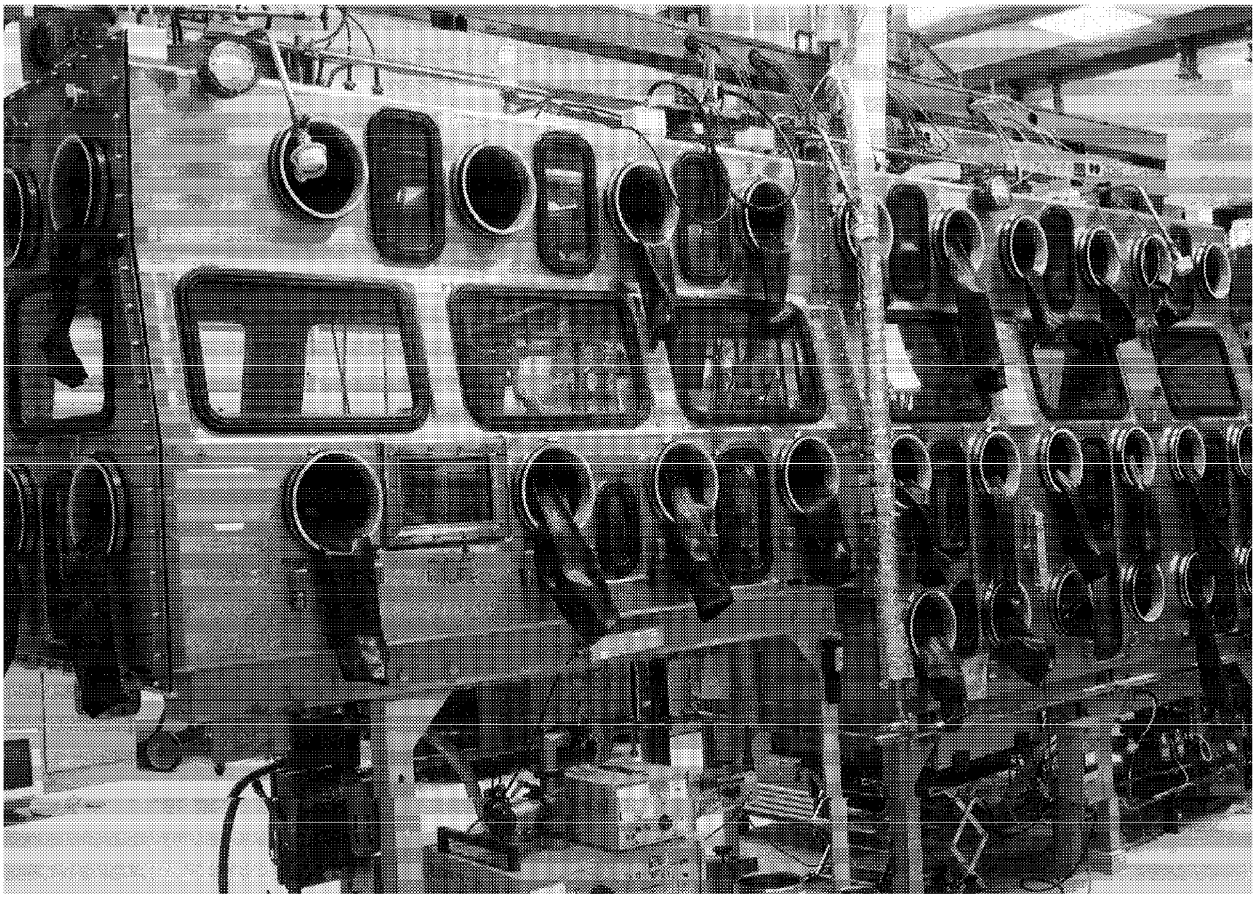

**Figure 10.2.2-1** **Shown is a typical glove box. This particular glove box is supported by a moment resisting frame composed of single angle legs. Frames of this type have been found to be vulnerable to seismic loads.**

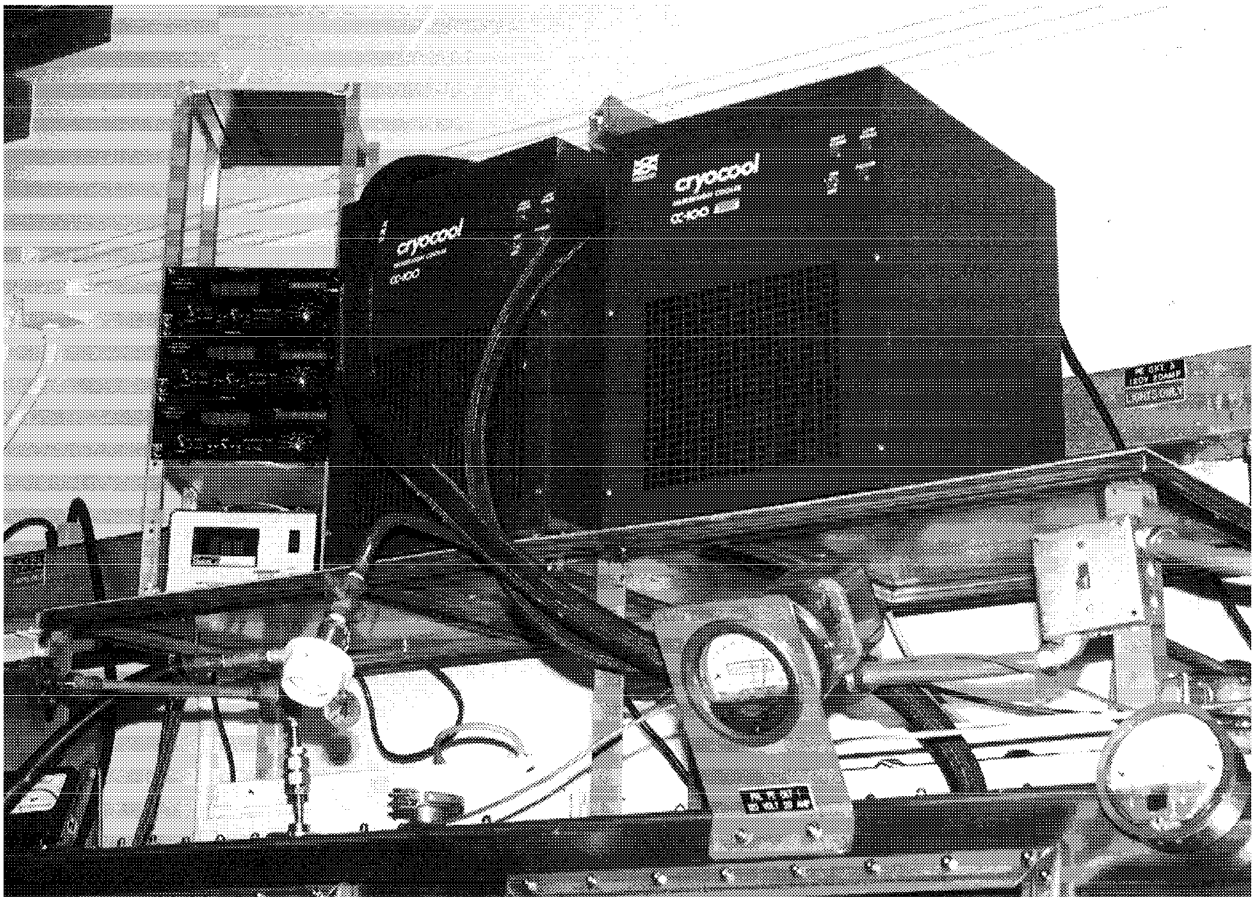


Figure 10.2.2-2 These refrigeration units support glove box activities. While the support stand is well supported on the top of the glove box, the units themselves are not anchored. During an earthquake, these units could slide off the support stand and impact a glove box window.

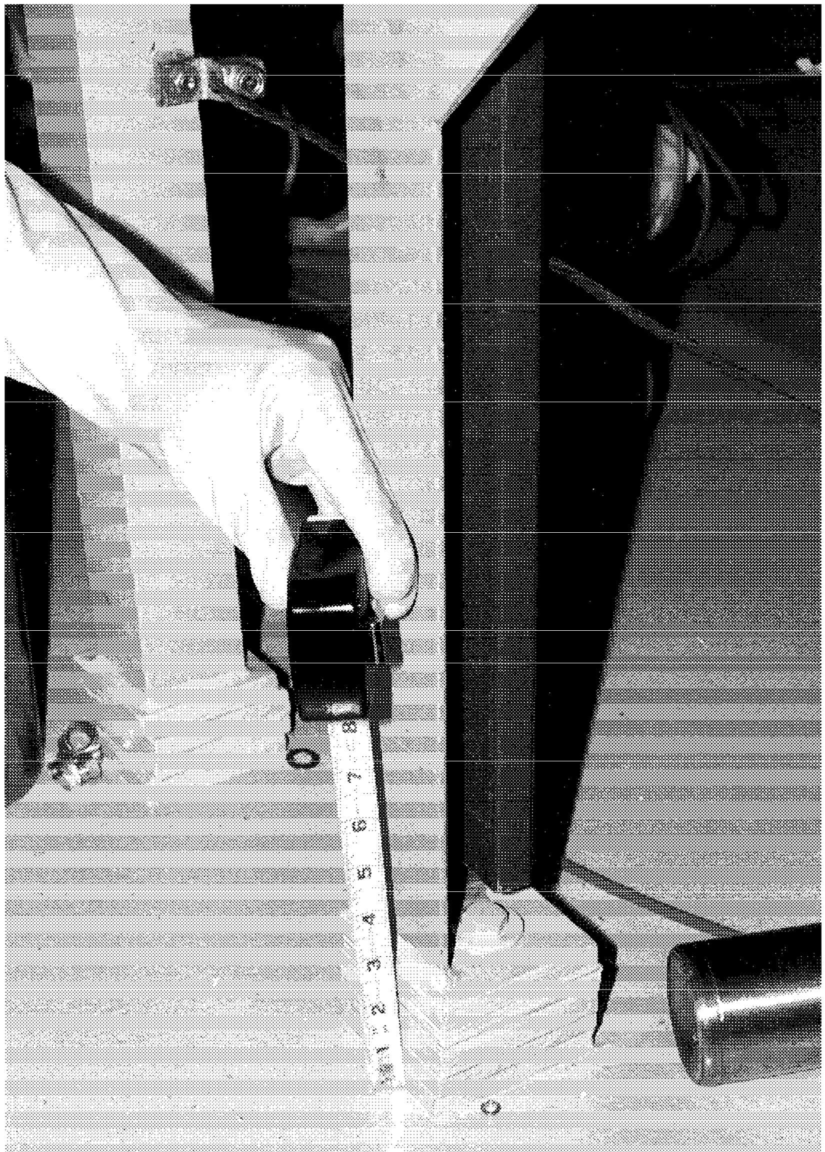

**Figure 10.2.2-3** **These legs have been shimmed to maintain proper vertical alignment of adjacent glove boxes. Excessive shim heights introduce bending to the anchor bolts which significantly decreases the bolt capacity.**

## 10.2.3 MISCELLANEOUS MACHINERY

This section describes general guidelines that can be used for evaluating and upgrading the seismic adequacy of miscellaneous machinery which is included in the Seismic Equipment List (SEL). The guidelines contained in this section are based on Section 4.9 of "Practical Equipment Seismic Upgrade and Strengthening Guidelines" (Ref. 60). Guidelines in this section cover those features of miscellaneous machinery which experience has shown can be vulnerable to seismic loadings.

Miscellaneous machinery is typically contained in a machine shop or maintenance facility. The machinery types in the facility include: lathes (see Figure 10.2.3-1), band saws (see Figure 10.2.3-2), drill presses (see Figure 10.2.3-3), and work bench mounted machinery.

Industrial grade machinery, such as that shown in Figures 10.2.3-1 to 10.2.3-3, is typically very rugged and does not experience significant damage during an earthquake as long as it is well anchored. The rugged machinery typically has an adequate load path for earthquake-induced lateral loads. Unanchored or inadequately anchored components can be susceptible to sliding, overturning, or component misalignment as shown in Figure 10.2.3-4.

Three general methods of evaluating and providing anchorage for shop and mechanical machinery are outlined below. The screening evaluation for anchor bolts is provided in Chapter 6 with the miscellaneous machinery typically treated as rigid. For miscellaneous machinery, the seismic evaluation should emphasize its anchorage.

- Anchor bolts should be provided through existing holes in machinery base. Bolt sizes should be the same as the size of the furnished holes and excessive amounts of shims should not be used.

- For tall, narrow, and/or top-heavy machinery which may overturn in a strong earthquake, anchors should be provided at all four corners, as shown in Figure 10.2.3-5.

- For short, wide, and/or bottom-heavy machinery which may slide but not overturn, bumpers should be provided at all four corners. As shown in Figure 10.2.3-5, bumpers should contact the edges of the machinery if possible. A resilient pad, such as neoprene, may be glued to the face of the angle to reduce impact loads.

Many miscellaneous machinery components are box-like units that simply rest on a concrete floor. A minimum of four anchor bolts should be provided for each item and the spacing between the anchor bolts should not exceed 4 feet. For machinery provided with base plates or structural members with holes intended for anchors, expansion anchors should be provided in these holes. Otherwise, new clips or angle can be either welded or bolted to the machinery and expansion anchors provided for the floor. For tall machinery, anchorage to a wall with adequate capacity in addition to that provided at the base can greatly increase the seismic capacity of the anchorage system.

There are many installation conditions for machinery in a machine shop or maintenance facility. General categories of the conditions include machinery on skids or wheels. Approaches which may be used to evaluate and upgrade the machinery in the two categories are presented below.

<u>Machinery on Skids</u>

Skids supporting machinery should be structural steel (or equivalent structural material) and the skids should be anchored to the floor slab with the machinery anchored to the skid. Stiffener plates should be supplied for steel skids which support heavy machinery to provide adequate stiffness to resist seismically induced lateral loads. Some recommended anchorage approaches are presented in Figure 10.2.3-6.

<u>Machinery on Wheels</u>

A number of different types of machinery, including maintenance machinery and computer consoles, are supported on casters or wheels. Without proper lateral restraint, machinery on wheels can roll around and damage other property and/or injure personnel. Wheel locks and an appropriate temporary restraining system, such as chains, should be provided for machinery that must remain mobile for operational purposes. Tall machinery should be anchored to the wall or roof at the top to prevent overturning. For more permanent items, floor or wall anchors should be installed, as shown in Figure 10.2.3-7. When anchoring to an existing wall, the capacity of the wall and the details of the structural connection of the wall and roof should be evaluated. If the wall is an unreinforced masonry (URM) wall, the provisions of Section 10.5.1 should be used.

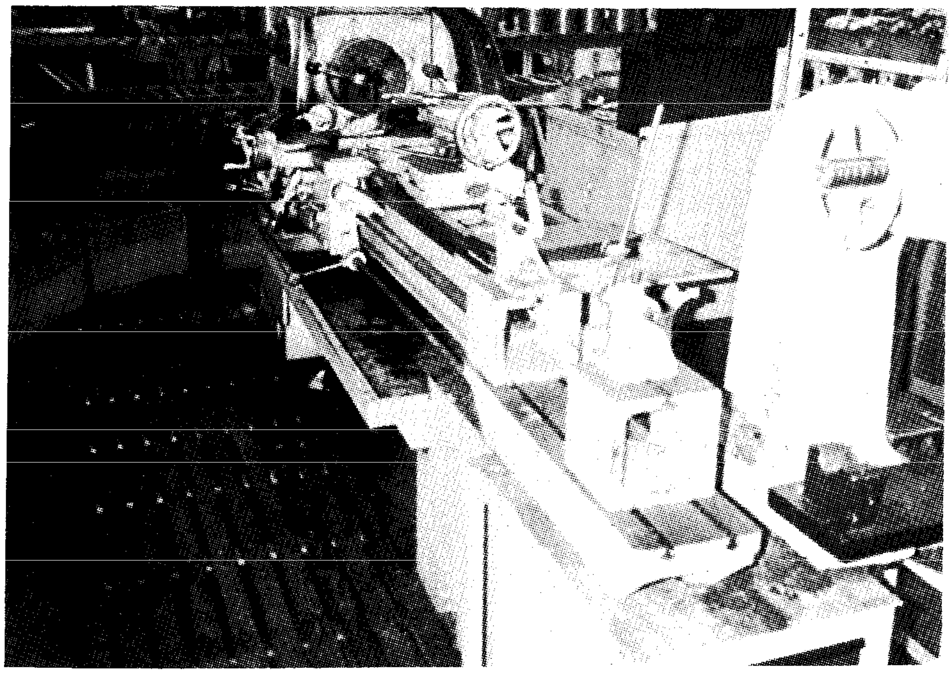

**Figure 10.2.3-1 Unanchored Metal Lathe Susceptible to Sliding (Figure 4-69 of Reference 60)**

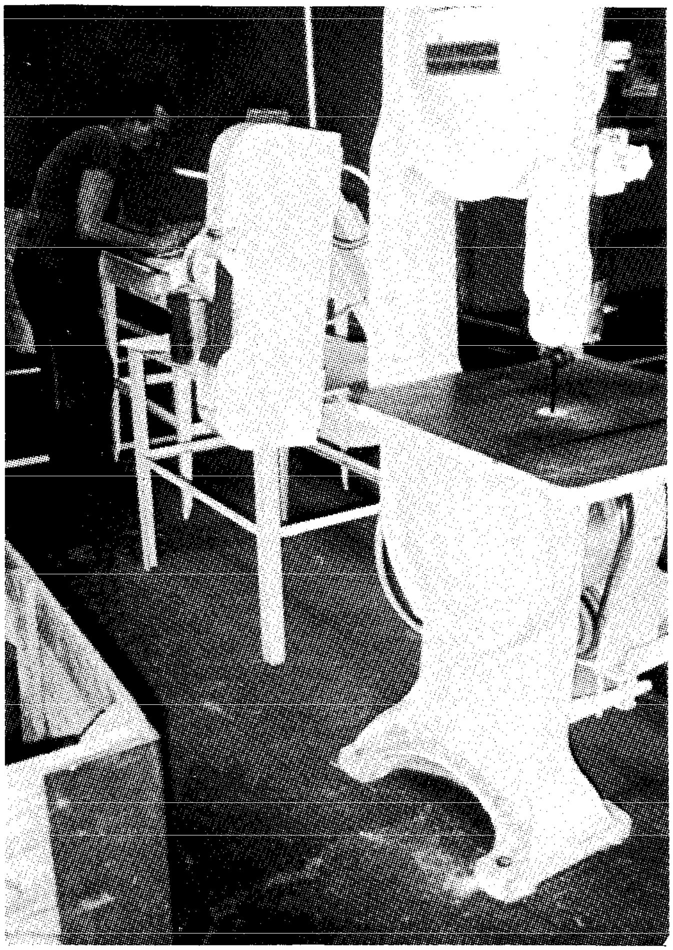

Figure 10.2.3-2 Anchored Band Saw
(Figure 4-70 of Reference 60)

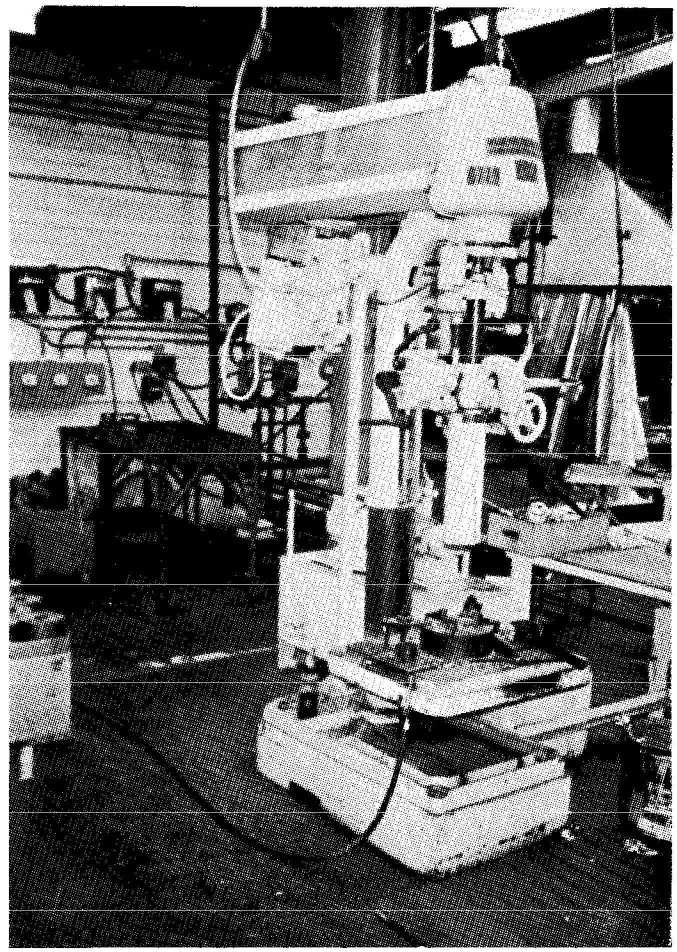

Figure 10.2.3-3 Unanchored Drill Press Susceptible to Overturning Damage
(Figure 4-71 of Reference 60)

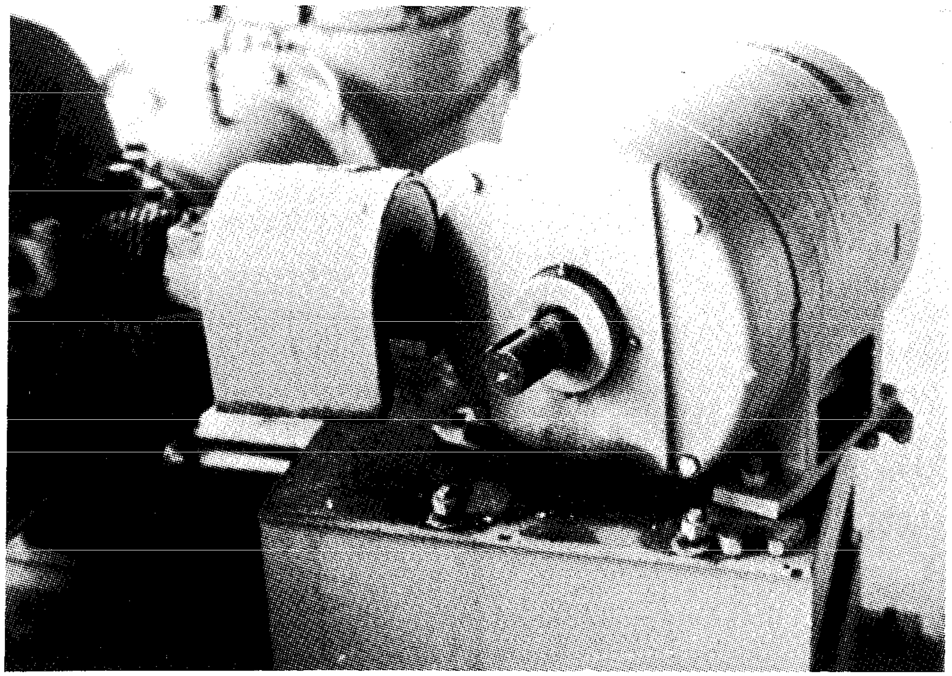

**Figure 10.2.3-4 Misaligned Electrical Motor Resulting from Improper Anchorage (Figure 4-73 of Reference 60)**

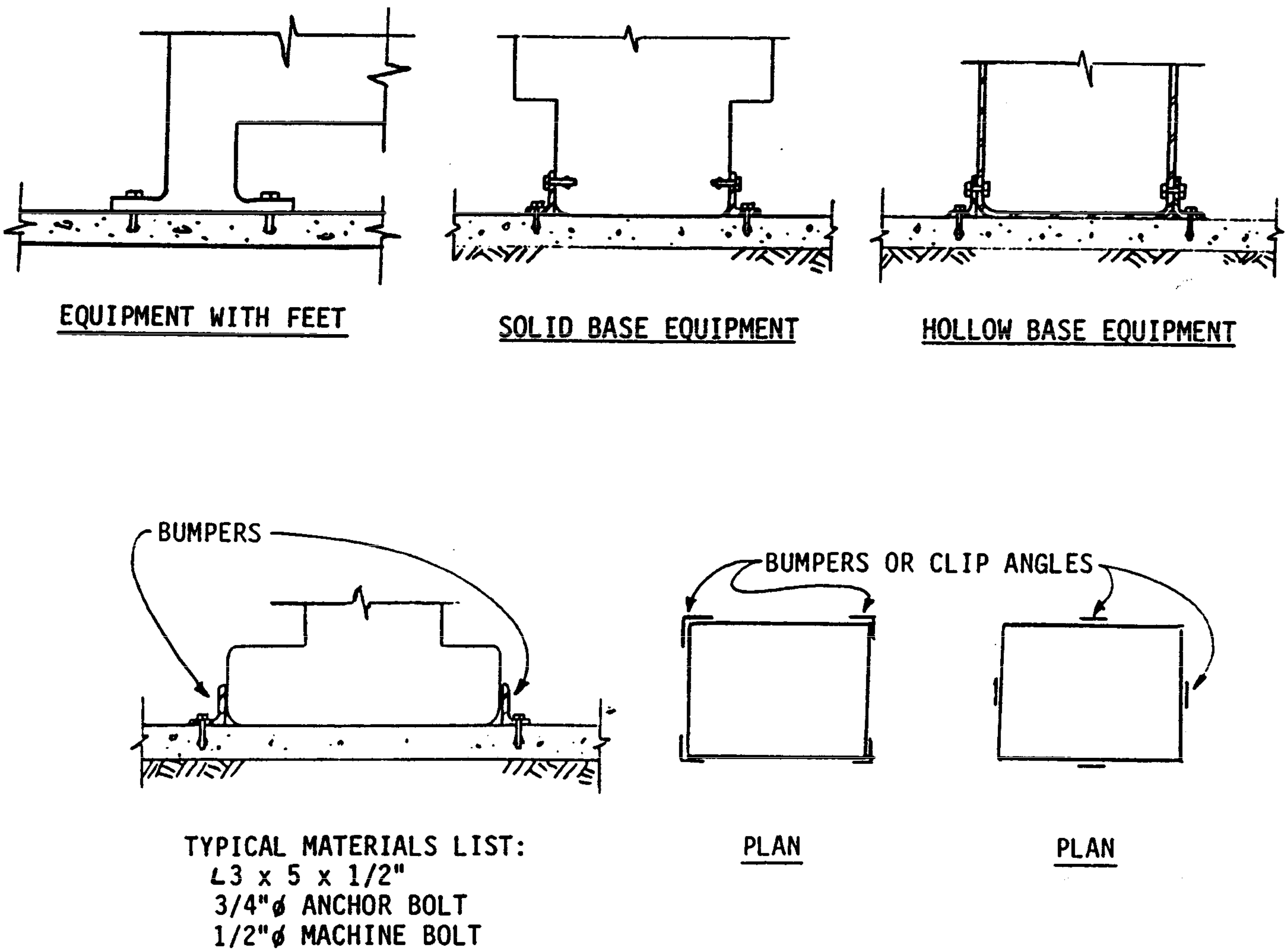


**Figure 10.2.3-5 Approaches for Anchoring Machine Shop Equipment (Figure 4-74 of Reference 60)**

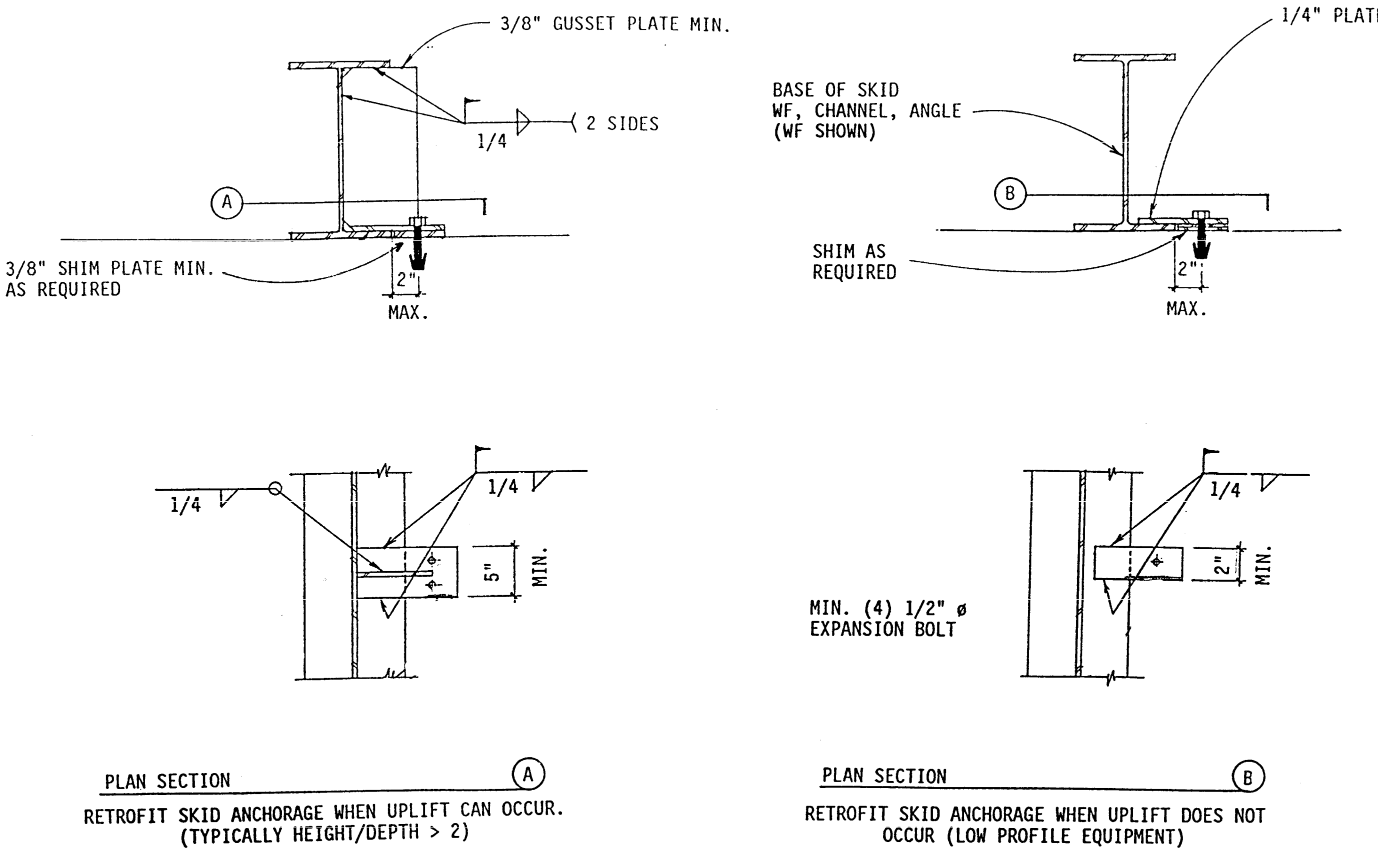


**Figure 10.2.3-6 Approaches for Anchoring Equipment Skids (Figure 4-76 of Reference 60)**

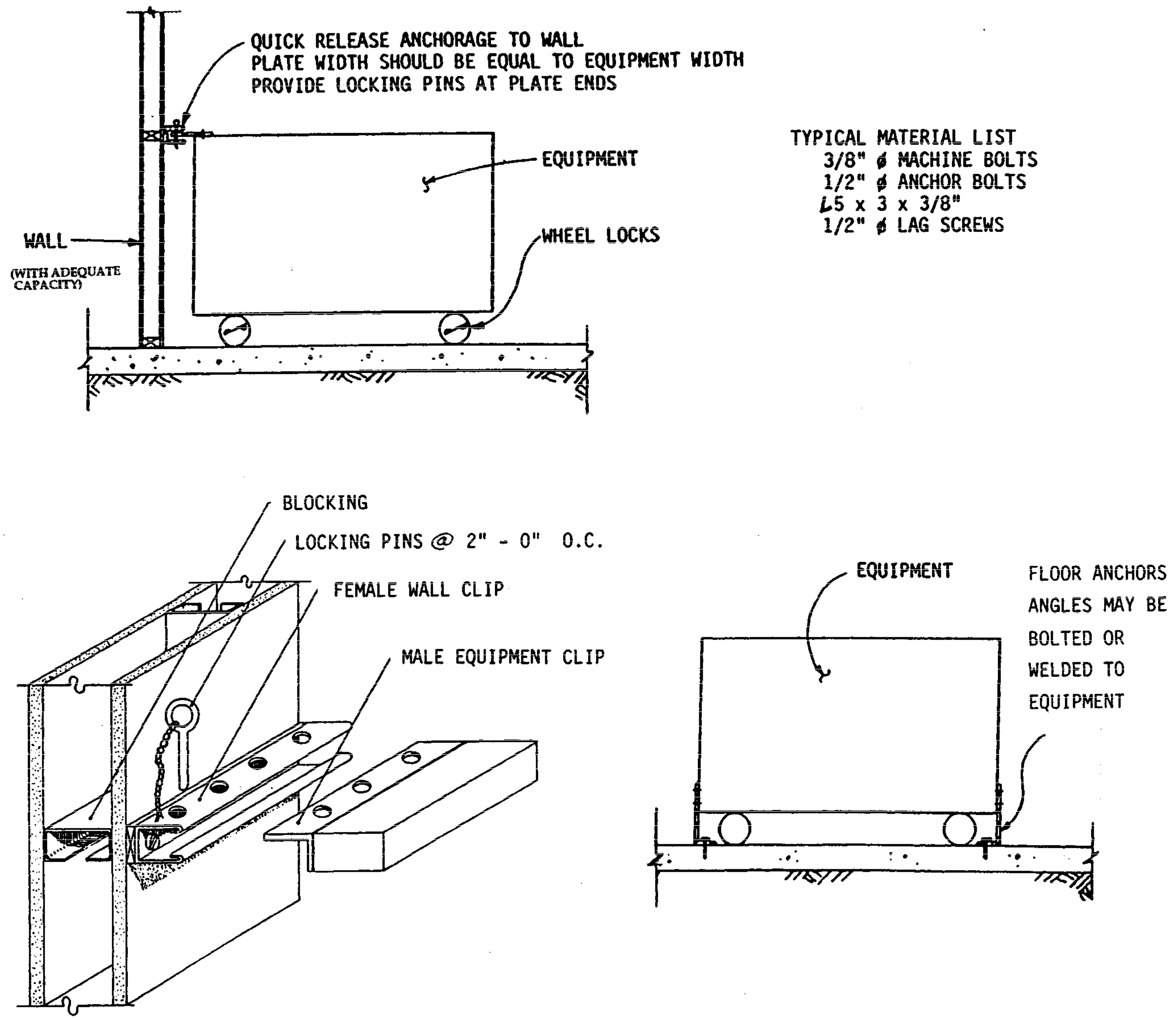


**Figure 10.2.3-7 Approaches for Anchoring Equipment on Wheels (Figure 4-77 of Reference 60)**